3D RECORDING FOR 2D DELIVERING
- THE EMPLOYMENT OF 3D MODELS FOR STUDIES AND ANALYSES -

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ABSTRACT:
In the last years, thanks to the advances of surveying sensors and techniques, many heritage sites could be accurately replicated in digital form with very detailed and impressive results. The actual limits are mainly related to hardware capabilities, computation time and low performance of personal computer. Often, the produced models are not visible on a normal computer and the only solution to easily visualized them is offline using rendered videos. This kind of 3D representations is useful for digital conservation, divulgation purposes or virtual tourism where people can visit places otherwise closed for preservation or security reasons. But many more potentialities and possible applications are available using a 3D model. The problem is the ability to handle 3D data as without adequate knowledge this information is reduced to standard 2D data.
This article presents some surveying and 3D modeling experiences within the APSAT project ("Ambiente e Paesaggi dei Siti d'Altura Trentini", i.e. Environment and Landscapes of Upland Sites in Trentino). APSAT is a multidisciplinary project funded by the Autonomous Province of Trento (Italy) with the aim documenting, surveying, studying, analysing and preserving mountainous and hill-top heritage sites located in the region. The project focuses on theoretical, methodological and technological aspects of the archaeological investigation of mountain landscape, considered as the product of sequences of settlements, parcelling-outs, communication networks, resources, and symbolic places. The mountain environment preserves better than others the traces of hunting and gathering, breeding, agricultural, metallurgical, symbolic activities characterised by different lengths and environmental impacts, from Prehistory to the Modern Period. Therefore the correct surveying and documentation of this heritage sites and material is very important. Within the project, the 3DOM unit of FBK is delivering all the surveying and 3D material to the interdisciplinary partners of the project to allow successive analyses or derivations of restoration plans and conservation policies.

Figure 1: Complex heritage sites and architectures in Trentino surveyed to produce maps, restoration plans and conservation policies.

1. INTRODUCTION

The importance of Cultural Heritage documentation is well recognized and there is an increasing pressure at international level to preserve them also digitally with long-lasting and standard formats. Indeed 3D data are today a critical component to permanently record the shape of important objects so that, in digital form at least, they might be passed down to future generations. This concept has produced firstly a large number of projects, mainly led by research groups, which have realized very high quality and complete digital models (Levoy et al. 2000; Beraldin et al. 2002; Stumpfel et al. 2003; Gruen et al. 2004; Guidi et al. 2006; Sonnemann et al. 2006; Ikeuchi & Miyazaki 2008; El-Hakim et al. 2008; Remondino et al. 2009) and secondly has alerted the creation of guidelines describing standards for correct and complete 3D documentations and digital preservation.
The technologies and methodologies for Cultural Heritage 3D documentation (e.g. photogrammetry or laser scanning) allow the generation of very realistic 3D results that could be used for many purposes, such as archaeological analyses, digital preservation and conservation, computer-aided restoration, virtual reality/computer graphics applications, 3D repositories and catalogues, web geographic systems, multimedia museum exhibitions, visualization and so on. Almost 50 years ago, the Venice Charter (International Charter for the Conservation and Restoration of Monuments and Sites, 1964) stated: "It is essential that the principles guiding the preservation and restoration of ancient buildings should be agreed and be laid down on an international basis, with each country being responsible for applying the plan within the framework of its own culture and traditions". But nowadays the need for a clear, rational, standardized terminology and methodology, as well as an accepted professional principle and technique for interpretation, presentation, digital documentation and presentation is still not established. Furthermore, "...Preservation of the digital heritage requires sustained efforts on the part of governments, creators, publishers, relevant industries and heritage institutions. In the face of the current digital divide, it is necessary to reinforce international cooperation and solidarity to enable all countries to ensure creation, dissemination, preservation and continued accessibility of their digital heritage" (UNESCO Charter on the Preservation of the Digital Heritage 2003). Therefore, although we may digitally record and produce models, we also require more international collaborations and information sharing to digitally preserve and make them accessible in all the possible forms and to all the possible users and clients.
But despite all these international statements, the constant pressure of international heritage organizations and the recent

advances of 3D recording techniques, a systematic and targeted use of 3D surveying and modelling in the Cultural Heritage field is still not yet employed as a default approach for different reasons:

1) the idea of high costs for 3D models;
2) the difficulties in achieving good 3D models by everyone;
3) the thought that 3D is an optional process of interpretation and an additional 'aesthetic' factor, i.e. traditional 2D documentation is enough;
4) the difficulty of integrating 3D worlds with other more standard 2D material;
5) the lack of powerful and reliable software to handle 3D data and produce standard documentation material

Since some years archaeological and architectural worlds are also entering the world of 3D surveying, processing and digital representation. But there are still some difficulties of communications between the geomatics people and these communities facing the 3D world. New technologies and new hardware are pushing to increase the quality of 3D models with the purpose of attracting new people into the 3D world. Many companies entered inside this market developing and employing software and survey systems with good potentialities and often very impressive results. Indeed the number of 3D products is huge and if one hand the cost of these technologies is slowly reducing, on the other hand it's difficult, in particular for non-specialists, to select the right product due to a lack of standard terminology and specifications. Furthermore, new technologies can for sure be a powerful tool to improve the classical standard of documentation and create a new methodology, however caution must be used and they have to be further studied and customized to be fully effective and useful, since even the standard bi-dimensional representations are still not problem-free (D'Andrea et al. 2008).

When planning a 3D surveying and modeling project, beside all the technical parameters that should be kept in mind (e.g. location, accessibility, geometric detail, budget), a very crucial thing to know is the final user of the 3D data and the final project's goal, in order to clarify what is actually needed. A complex archaeological structure surveyed and modelled with very high definition and huge data set may appear charming but, for example, it can produce problems in the data visualization and handling. So many hours of surveying and processing are lost to produce an impressive and metric 3D model which is then subsampled and strongly reduced in geometry because it cannot be used.

The article, after a quick review of the actual 3D recording techniques, presents a critical overview of recent 3D modeling studies performed in the Trentino region (NE of Italy) within the APSAT project. The interdisciplinary project involves archaeologists, engineers, surveyors and architects. i.e. a mix of different cultural backgrounds, languages and needs. Aware of all the aforementioned problems, we tried to contribute exploiting the use of actual surveying technologies (laser scanners, digital cameras, GNSS, etc.) to their maximum potentialities for what concerns speediness and accuracy and at the same time trying to find the fastest procedures to optimize the use of the acquired 3D data to derive records more useful and usable by architects or archaeologists like geometric primitives, counter lines, 2D sections, maps and so on.

2. 3D SURVEYING TECHNIQUES

Nowadays there is a large number of geomatics data acquisition tools for mapping purposes and for visual Cultural Heritage digital recording. These include satellite imagery, digital aerial cameras, radar platforms, airborne and terrestrial laser scanners, UAVs, panoramic linear sensors, SRL or consumer-grade terrestrial digital cameras and GNSS/INS systems for precise positioning. Beside data acquisition systems, today new software have been developed and many automated data processing procedures are available. For what concerned new functionality for 3D data management, there are new advances in Geographic Information Systems (GIS) and 3D repositories (e.g. BIM) while in the visualization field the rendering and animation software are now more affordable and performance, with lower costs and higher results.

The continuous development of new sensors, data capture methodologies and multi-resolution 3D representations are contributing significantly to the documentation, conservation, and presentation of heritage information and to the growth of research in the Cultural Heritage field. The generation of reality-based 3D models of heritage sites and objects is nowadays performed using methodologies based on passive sensors and image data (Remondino and El-Hakim 2006), active sensors and range data (Blais 2004; Vosselman and Maas 2010), classical surveying (e.g., total stations or GNSS), 2D maps (Yin et al. 2009), or an integration of the aforementioned techniques (El-Hakim et al. 2004; Guidi et al. 2004; De Luca et al. 2006; Stamos et al. 2008).

The choice or integration depends on the required accuracy, object dimensions, location constraints, instrument's portability and usability, surface characteristics, project's budget and final goal of the 3D survey. Identify the best approach in every situation is not an easy task but it is nowadays clear that the combination and integration of different sensors and techniques, in particular when surveying large and complex sites, is the ideal solution (Gruen et al. 2005; El-Hakim et al. 2007; Rönholm et al. 2007; Guidi et al. 2009) in order to: (i) exploit the intrinsic strengths of each technique, (ii) compensate for weaknesses of individual methods, (iii) derive different geometric Levels of Detail (LoD) of the scene under investigation that show only the necessary information and (iv) achieve more accurate and complete geometric surveying for modelling, interpretation, representation and digital conservation issues.

3. CASES STUDIES

3.1 Ossana castle

The Ossana castle (Figure 2) is located in the Sole Valley, a mountainous area in the north-west of Trentino.

Figure 2: The Ossana castle with its complex and partly demolished structures.

The heritage is on top of a small hill close to the houses of the village of Ossana and it has unique and fascinating structures of a complex architectural style which has evolved over centuries. The castle is formed of complex wall structures and in the interior yard many structures are almost demolished or covered by protections and scaffoldings.

Three-dimensional modelling aims at capturing all the geometrical details (both exterior and interior) and representing these features with high-resolution triangular meshes for accurate documentation, photo-realistic visualisation, generation of restoration plans and conservation policies in accordance with the project specifications and requirements.

The surveying methodology (Figure 3), based on the experience acquired in similar past projects (Remondino et al., 2009), employed terrestrial range-data as one of the primary project needs is to identify and catalogue even small areas of the heritage and analyse the stones geometry. Furthermore, a new map of the heritage structures must be realized and compared with the existing one to determine structure changes and evaluate the potentiality of the range-based surveying methodology for this application. Therefore, for all these reasons, a photogrammetric approach was not suited and adequate.

A TOF terrestrial laser scanner (TLS) was used for massive and dense data collection of the castle shape and surrounding landscape. A TLS survey at an average of 1 cm geometric sampling step was realized for all the sides of the structure. The acquisition has been influenced by some limitations due to occlusions and unfavourable location of the structure. Some parts of the external walls could not be surveyed due to inaccessibility reasons. One of the most important issues was to determine the most suitable spatial resolution for the surveying. This depends on the desired level of detail as well as the scene's size, shape, complexity and occlusions.

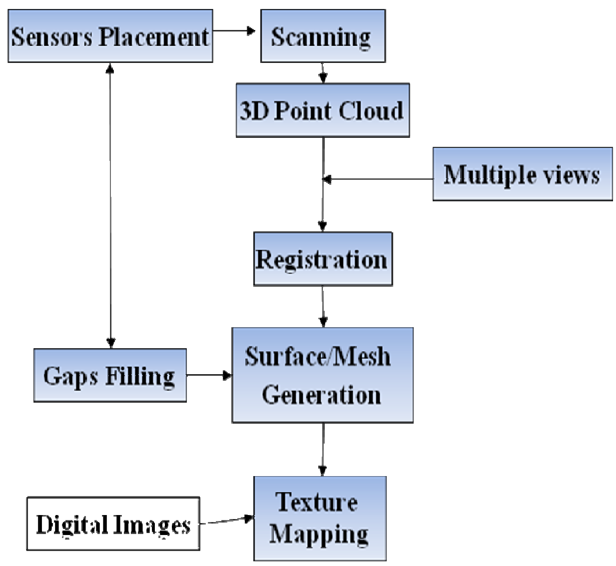


Figure 3: The employed range-based methodology for large and complex structure 3D surveying and modeling

From 43 stations, more than 70 million points were acquired, cleaned, aligned, georeferenced (by means of some GCPs) and converted into a polygonal mesh for texturing purposes (Figure 4). For the texturing, high resolution RAW images (24 Mpx) were acquired and radiometrically calibrated in order to fulfil the needs of creating a photo-realistic digital replica of the surveyed heritage. Indeed for Cultural Heritage it is very important to reproduce the true colour of the surveyed scene. 3D models generally should represent a virtual copy of the scene, i.e. an accurate shape reconstruction overlapped by a precise colour mapping.

Figure 4: The complete 3D model of the heritage, visualized as shaded and colour mode.

Figure 5 shows a detail of the produced geometric polygonal model for the main tower and the external walls. It is possible to observe the great detail of the surveyed structures, achieved following the project specifications defined by archaeologists and architects. This is often an overkilling decision, in particular considering the fact that non-experts are not able to read and use such detailed and high resolution 3D data and all the surveying efforts are then reduced to 2D plans.

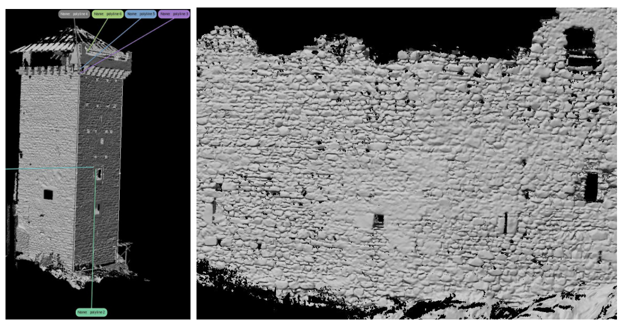


Figure 5: A geometric detail of a modelled tower and walls.

From the 3D data, using standard CAD procedures, an up-to-date and detail map of the heritage structures was produced (Figure 6). Comparing this result with an old cadastral map realized with a traditional total station approach, it's possible to identify the structure changes and, more important, the higher detail achievable with the range-based method (Figure 7).

Certainly the achieved results are good, detailed and accurate. It is a bit ludicrous the fact that 3D models are not yet fully exploited with all their benefits and properties for architectural and archaeological applications or analyses and very often the 3D data need to be reduced to 2D due to a lack of knowledge and software to handle such rich geomatics information. A solution could be a fully 3D GIS tool which allows the user to easily and fluently move the 3D model, interact with it and make queries.

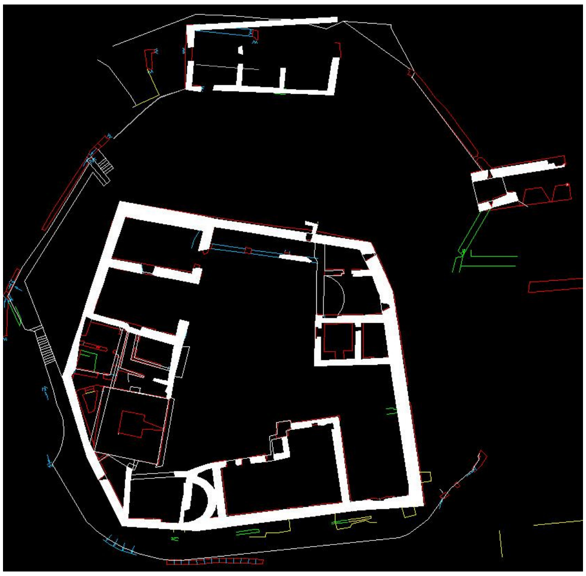


Figure 6: The new map (white and thick walls) of the heritage derived from the range-based 3D model, superimposed onto the old cadastral map.

Figure 7: Some differences between the two maps, due to low resolution surveying but also structural changes (in white the more accurate and detailed range-based results).

3.2 The village of Calvola di Tenno

The medieval village Calvola di Tenno (Figure 8) is a very nice place, entrenched on a mountain slope halfway between the Garda lake and the Alps. Narrow, paved alleys, arcades, small internal squares and houses are set one against the other like in the ancient villages of the 13th century. The village was abandoned after the WW1, but in the Sixties of last century it came back to life. Most of the town has not been touched by the passing of time and for this reason it is very interesting for archeological studies. The 3D surveying is necessary to produce new maps, sections and orthophotos of the buildings façades in order to understand, identify and classify which architectural elements are original and which are instead new. Furthermore, every transitional phase of the village needs to be reconstructed with the purpose of identify the principal block where Calvola's village started. At first glance, the village might seem quite small but, considering the area and the structures to be surveyed, it reveals itself indeed as a challenging task. The village occupies an area of ca 4 km^2 with approximately 30 buildings located on a gently slope of a hill (Figure 8 and 9).

Figure 8: An aerial view of Calvola di Tenno.

The survey started with a terrestrial photogrammetry approach, but after the first campaign we abandoned it because of the difficulties in achieving a good network geometry, mainly due to the very narrow streets and houses closely nestled together which made image-based approach inadequate and time consuming. Digital images were nevertheless acquired for each single façade to produce orthophotos.

TLS methodology has already shown good results in similar projects (Barber et al., 2002; Bitelli et al., 2002; Drap et al., 2003; Guidi et al., 2002). For this reason there is an enormous potential for such 3D recordings methodology in these kind of applications where dense point clouds could provide an optimal surface description in the framework of archaeological and architectural recordings.

But although laser scanning data can easily provide surface models for orthophotos, thus eliminating the need for lengthy photogrammetric surface extraction and editing, it is important to ensure that the resolution of a laser scans is high enough that the features of interest are visible in the acquired point clouds.

The dimensions of the site and the integrity of the structures need also to be considered, in order to reduce the surveying time on site and define the most suited geometric resolution of the scanning. With this is mind, the average sampling step of the range acquisitions was set at 2 cm due to the large area to be recorded and as the structures are integer, without any piles of rubble or cracks like in the Ossana castle.

The laser scanner data acquisition was performed with a Leica Scan Station 2, mounted on a home-made trolley (Figure 10 a) to reduce the set-up time between every scan position and speed up the surveying. Altogether 55 stations (for globally 67 million points) were necessary to capture the entire village. Although we were using a trolley, it was very difficult to cover all the areas due occluded or not-accessible areas and the geometrically complex structures (Figure 10 b, c). Some GNSS points were also acquired for the geo-referencing of the 3D data in the WGS84-UTM32N coordinate system.

The range data were processed in Cyclone and Polyworks. Data registration is the critical and manual process of tying single scans with their own local coordinate system, defined by the individual scanner location and orientation, into a combined point cloud. The software provides the tools to perform a coarse registration by common points and the successive fine alignment with an ICP algorithm, upon which a polygonal model can be created (Figure 11).

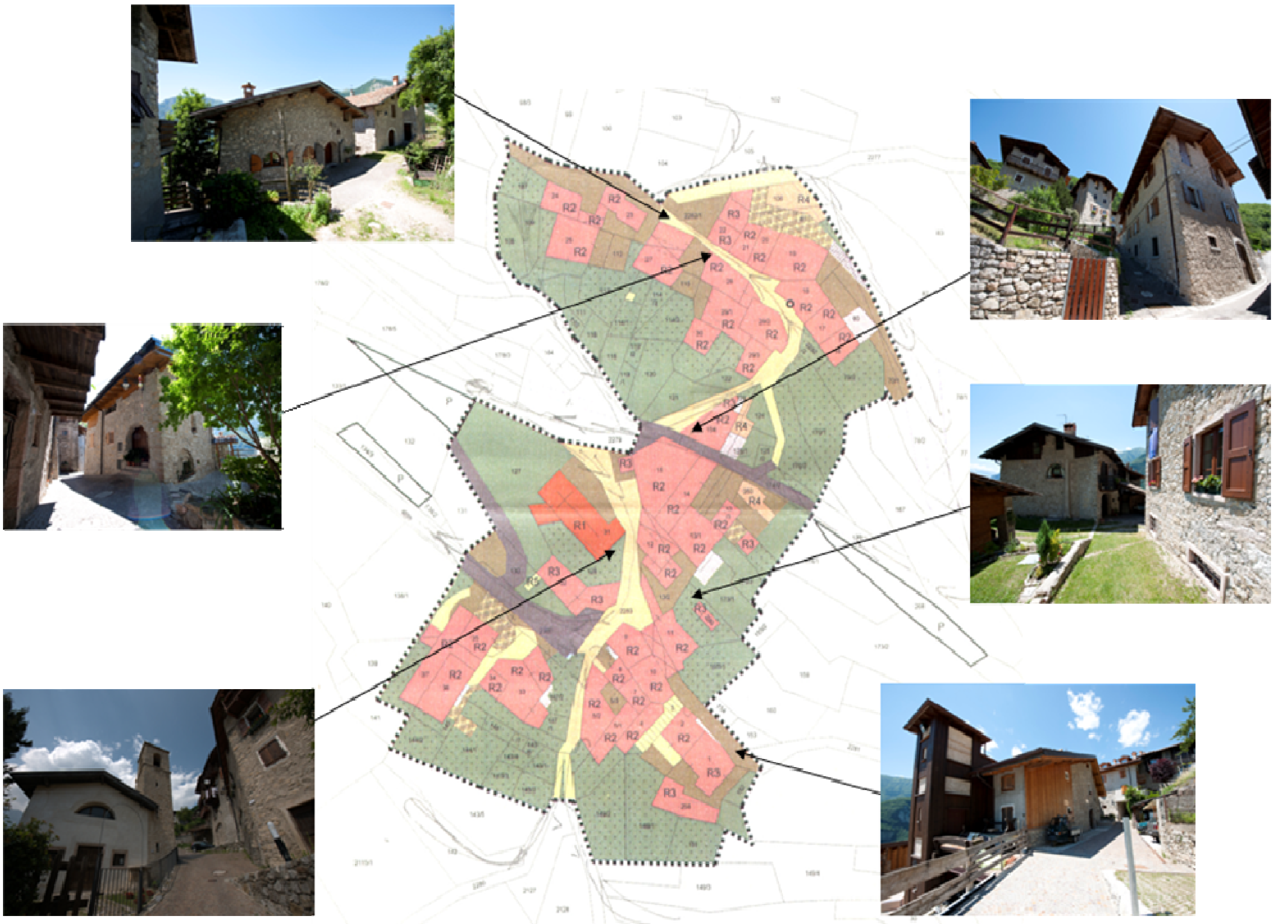


Figure 9: The village of Calvola, in an old cadastral map of the early XIX century (Asburgic period), with some picture showing its narrow streets, court yards, stone houses, overhanging roofs, occlusions, etc.

a) b) c)

Figure 10: The laser scanner on the home-built trolley (a). Not-accessible areas which required to place the surveying instrument is difficult positions (b, c).

Finally a texture model is created using the high-resolution images. The result is a huge 3D model with few holes and very difficult interaction possibilities due to its size.

The produced 3D model of the village is then the base for the successive architectural and archaeological analyses. From the 3D model, we could produce:

- orthophotos of some façades and walls, allowing the architects to study the architecture of the buildings in bi-dimensional space and produce vector data (Figure 12);
- a cadastral map to highlight the differences (shifts up to 2 meters) with existing plans and produce up-to-date cartographic information of the village (Figure 13).

The surveying and modeling work produced a complex 3D model which was finally reduced (using CAD packages) to 2D information for the successive analyses. Indeed complex and detailed 3D models, at the moment, can only be easily handled with graphic packages which lack of many functionalities very useful for basic mapping purposes.

Nevertheless, the final model of the Calvola is an accurate and three-dimensional representation of the actual state of the village, which could be useful in the near future and certainly offers potentialities for further analysis regarding even (now not yet explored) three-dimensional aspects.

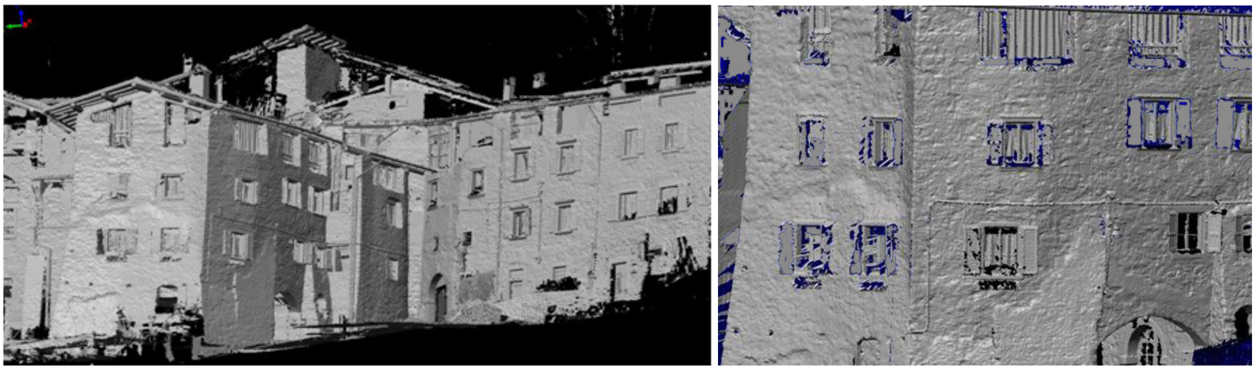
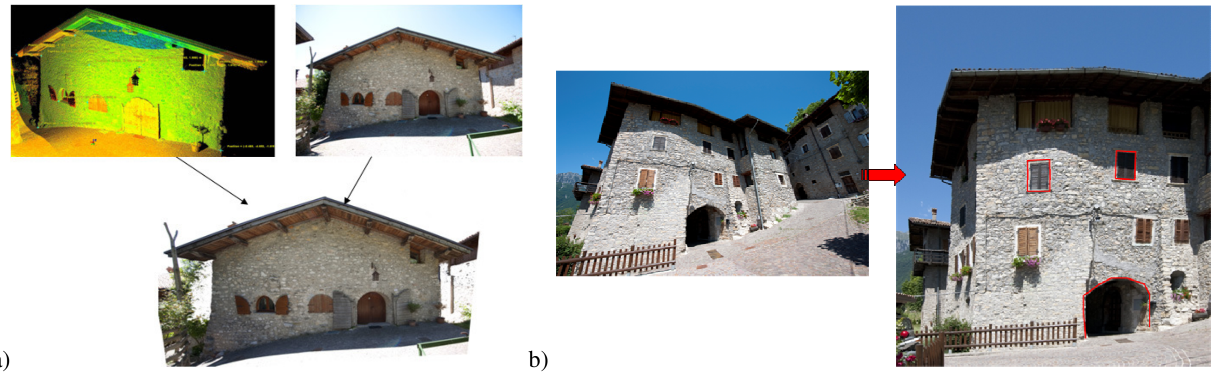


Figure 11: Some 3D results for the Calvola village. For such complex structure, the hole filling procedure is the most time consuming part of the 3D modeling pipeline.



a) b)

Figure 12: Range and image data co-registered to create an orthophoto of the façade (a). Produced orthophoto and vectorialization of architectural information (b).

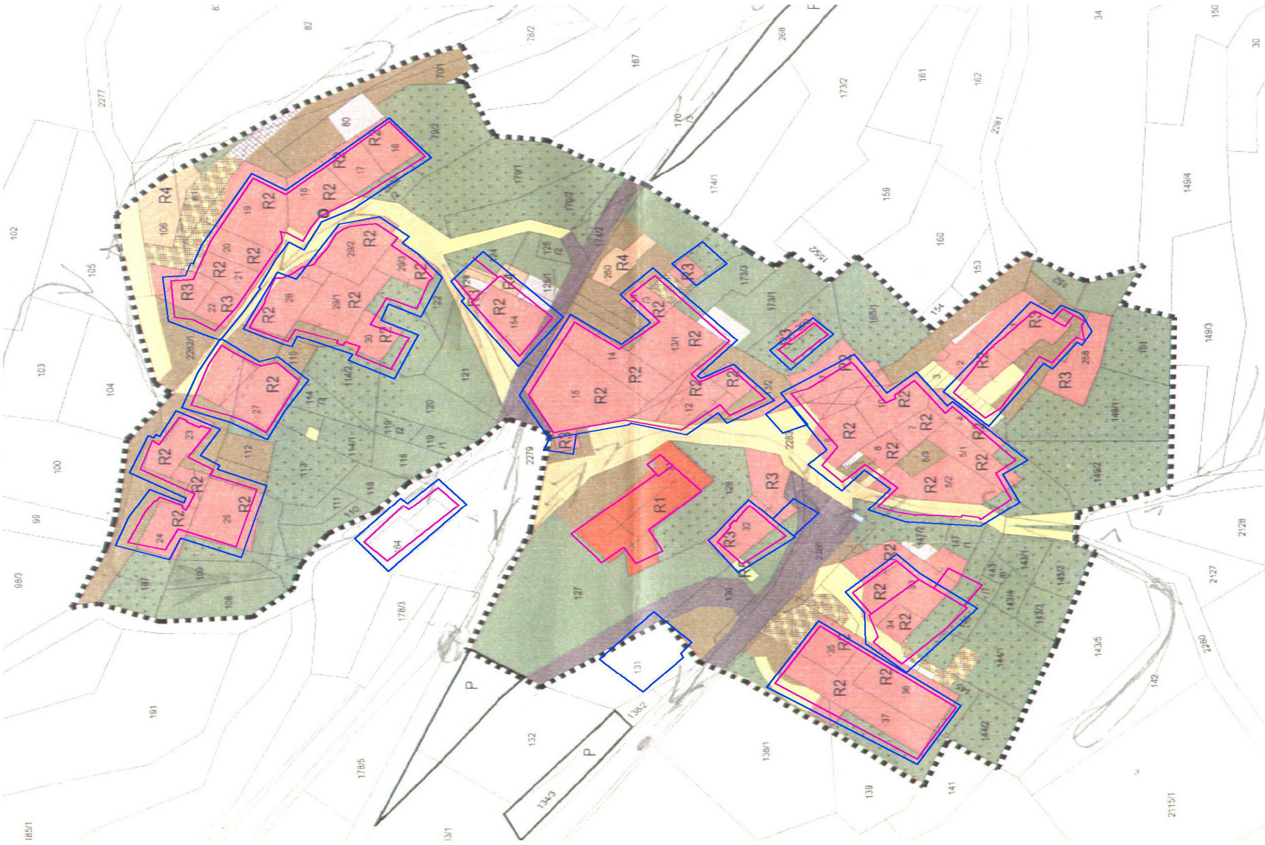


Figure 13: The superimposed building contours (derived from the laser scanning data) onto the existing map of the village. Remarkable shifts and differences are clearly visible.

3.3 San Pietro castle

The last case study is the castle of St. Peter, a medieval building (ca 50 x 30 m) of the 12th Century, built by the Thun family and abandoned in the 17th Century. Rising at 860 m. a.s.l., the building dominates the St. Peter valley in a harsh environment at the western slopes of the mountains that divides the Valle di Non and the Valle d`Adige. Currently, only the ruins of the castle can be seen (Figure 14).

Figure 14: The castle location and a part its ruined structures.

Due to occlusions, irregular surfaces and the requirements to deliver contours even for the surrounding terrain, the surveying is performed with a TOF laser scanner (Leica Scan Station 2), a much faster and reliable 3D recording instrument in the aforementioned conditions. Digital images are acquired separately in order to produce orthophotos of the vertical structures for architectural and archaeological purposes. The unfavourable location with a difficult accessibility required the use of donkeys to transport all the surveying instruments. The range data consist of approximately 8 million points, acquired from 15 different stations with an average sampling step on the structures of 2 cm. After editing cleaning, alignment and geo-referencing, the final point cloud is converted into a polygonal mesh consisting of more than 9.5 million triangles, which are classified in different groups (both natural and man-made) that compose the whole heritage structure. From the 3D model and according to a global reference system, contours with an equidistance of 10 cm are produced for each classified group. The resulting data are then imported into CAD packages, classifying the various architectural structures on the basis of their spatial characteristics, enabling the display of any section or prospectus. To highlight the terrain's slope around the castle, 3D polyline in planimetric view are used. The final results required by the project partners consists of two-dimensional drawings (Figure 15), produced from the 3D data through a LISP application. Finally the orthophotos were also included primarily to define and highlight the contours of the morphological and architectural features of the remaining building structures. All the achieved 2D results are now used by archaeologist and architects to produce up-to-date and detailed documentation material of the heritage as well as conservation plans and restoration policies.
This case study underlines some actual problems and challenges still open in the surveying community. The first one is the complexity of an intricate and ruined structure like St. Peter castle for 3D recording applications, not only for its location, terrain morphology and irregular shapes, but also because of the density of vegetation around the field, all factors which made the surveying difficult and increased the time and manner of data acquisition and, in particular, data processing/editing. Furthermore the delivering of 2D information (plans, sections, maps, contours) derived from 3D data highlighted the fact that actually not many persons can really use 3D models and exploit all their potentialities and contents. Probably the visualization is the only real application where a 3D model can be used by everyone, but when it comes down to structure analysis, restoration and conservation studies, due to a lack of proper software packages, 2D material is still the most required material.

4. CONCLUSIONS

The presented case studies described the entire pipeline from on-site 3D data acquisition to 2D data delivering for architectural and archaeological applications. The examples featured only terrestrial laser scanning (TLS) as 3D surveying technique. Airborne laser scanning was excluded mainly due to the high costs of the acquisitions and the not sufficient ground resolution. Terrestrial photogrammetry was a cheaper and more convenient solution but the irregular shapes and complex structures to be surveyed would have required very long processing time. Aerial photogrammetry or high-resolution satellite imagery were not suitable due to the low resolution of the image data, the many occluded areas and the necessity to survey facades and vertical walls.
The realized range-based 3D geometric models - although geometrically accurate and detailed - are not very much useful to archaeologist and architects due to a lack of proper software. Indeed these communities are still dealing with traditional 2D information as 3D-related products are not yet efficiently managed for their needs. For this reason a methodology (Figure 16) was developed in order to deliver standard 2D products like contours, sections and maps. The procedure is automated in certain steps but most of the work needs the user assistance. From a software point of view, there is a lack of an efficient and reliable package able to perform all the required procedures and analyses. Therefore multiple packages must be used, with significant problems of compatibility and data formats. Recently some commercial packages were presented with some features to handle 3D point clouds or meshes and derive geometric primitives but we were not really satisfied of the performances. The future is in any case in this direction, trying to exploit all the advantages and information contained in 3D models. The research community and software houses need to develop the appropriate methodology to compensate for the loss of time with the reduction from 3D data to 2D.

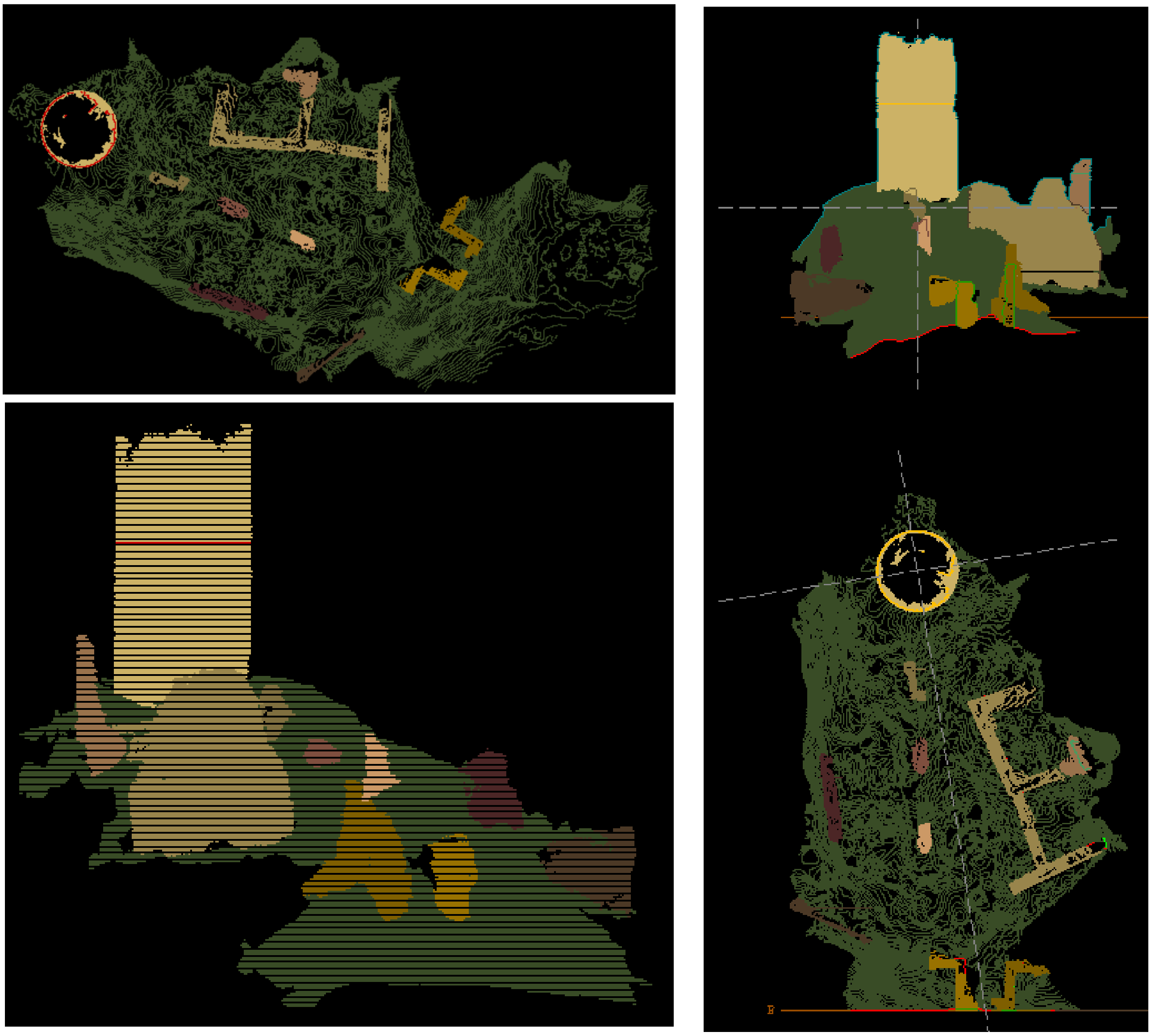


Figure 15: Contours (10 cm interval) and sections realized for architectural purposes and to create conservation and restoration plans.

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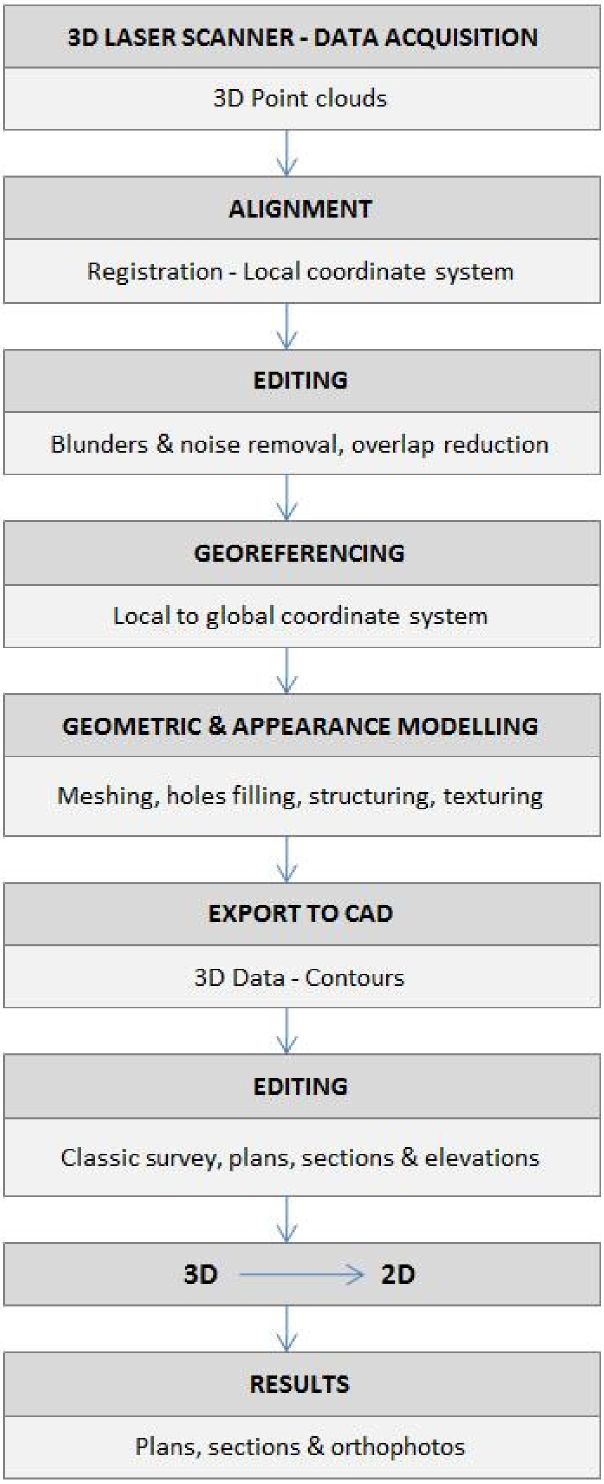

Figure 16: The flowchart of the methodology followed for the 3D surveying of complex heritages and the delivering of 2D results.

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